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Evaluation on Service Quality of Railway Timetable

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Abstract

From the business viewpoint, the railway timetable is a list of the products presented by the railway transportation operators to the customers, specifying the schedules of all the train services on a railway line or network. In order to evaluate the quality of the train service schedules, a number of indices are proposed in this paper. These indices primarily take the passengers' need into consideration, such as waiting time, transfer time and transport capacity. Delay rate is usually used in post-evaluation. In this study, we propose to give an evaluation on the probability that the scheduled train services are likely to be delayed and the recovery ability of the timetable after delay has occurred. The evaluation identifies the possible problems in the services, such as excessive waiting time, non-seamless transfer, and high possibility of delay. This paper also discusses the improvement of these problems through certain adjustment on the timetable. The indices for evaluation and adjustment method are then applied to a case study on the Hu-Ning-Hang railway in China, followed by the discussions of the merits of the proposed indices for timetable evaluation and improvement method.

Keywords: Railway timetable; Train service; Evaluation

INTRODUCTION

From the business viewpoint, the railway timetable is a list of the products presented by the railway operators, which specifies the schedules of all the train services on a railway line or network. As in any business transaction, the customers have requirements and hence expectations on the products they buy, they demand the train services they choose to be consistent with the specifications stipulated in the timetable. As a result, the service quality implied by the timetable

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is great concern of the railway operators.

Quantitative parameters of the timetable, such as the number of train services scheduled, daily train-kilometer of the passenger and freight train, average traveling speed of the various train services, average daily locomotive-kilometer and the daily number of the locomotives required used to be investigated (Yang, 2001). In recent years, studies are apt to concern the indices like punctuality, delay propagation and robustness. The evaluation of the robustness involved three factors, the extra-delayed time of a train , the trains involved by delay and the critical train service (Peng, 1998). Goverde (2007) presented a stability theory to analyze the sensitivity and robustness of the timetable to delays based on a linear system description of a railway timetable in max-plus algebra. Wendler (2007) utilized a semi-Markovian queuing model to predict the scheduled waiting time. Vansteenwegen (2007) proposed a model to minimize waiting cost function that includes running time supplements and different types of waiting times and late arrivals.

However, the studies above mostly concern only one or two criteria and rarely involve the optimization on the train service schedules. In order to improve the quality of the railway timetable from the viewpoint of the passengers, more criteria and practical adjustment methods are to be considered. In this study, criteria of time cost, transportation capacity, delay probability and robustness will be discussed. A multi-objective model for the timetable enhancement will be proposed consequently.

CRITERIA

Time cost

(1)Waiting time at stations (T_1)

By supposing the passengers get to railway station stochastically, the mean waiting time will be half of the cycle time T_c for periodic timetable; while for a non-periodic timetable, it will be half of the interval time T_v of the two trains in the same direction. The reason is that, the longest waiting time is T_c or T_v, and shortest waiting time is 0. Since they get to the station stochastically, the waiting time T_1 is

$$T_1 = \begin{cases} T_c / 2, & \text{for periodic timetable} \\ T_v / 2, & \text{for nonperiodic timetable} \end{cases} \qquad [1]$$

(2)Travel time (T_2)

Travel time is the total time that the passengers spend on the way from the starting station to the destination. It includes two parts, one is the running time, and the other is the dwell time.

$$T_2 = \sum T_i^r + \sum T_i^d \qquad [2]$$

where T_i^r and T_i^d are the running time and dwell time of ith train respectively.

(3)Transfer time (T_3)

The transfer discussed here refers to the interchange between one train and another at the same station. The time that passengers wait for the connection train is used to measure the seamlessness of the connection. The total and average transfer time planned by a timetable is given below.

$$T_3 = \sum_{(i,j)\in\Omega^c} (T_j - T_i) \qquad [3]$$

$$\overline{T}_3 = \frac{T_3}{n_c} \qquad [4]$$

where (i, j) is a connection train pair; T_i and T_j are the times of events i and j respectively; Ω^c is the set of connection train pairs and n_c is the number of its entries.

Transport capacity

The railway operator is supposed to satisfy all the Transportation Demand (TD). In other words, the capacity of the train services should meet the TD.

$$C_t \geq \eta D \qquad [5]$$

where C_t is the capacity of the trains scheduled by the timetable; η is the comfort factor to adjust the level of service; D is the TD. If η=0.8, C_t is lower than the TD, then it will be crowded in the trains; if η=1.2, the space for the passengers on the trains will be more comfortable. C_t is computed by

$$C_t = \sum c_i = n\overline{c} \qquad [6]$$

where c_i is the capacity of ith train; n is the number of train services scheduled by the timetable; $\overline{c}$ is the average train capacity.

Delay probability

The exponential distribution is used to model the train delay probability (Vansteenwegen, 2007). The delay probability given by exponential distribution only represents the intrinsic delay without the influences by external factors. However, the running of a train is inevitably affected by other trains. Here, *pre*(x) i.e. pre-set of a train active event x is defined as the set of trains that influence the event x. For instance, on a train service diagram as illustrated in Figure 1, x_i denotes the ith event of departure event. The pre-set of event x_8 is $pre(x_8)=\{x_2, x_7\}$. Let $\|pre(x)\|$ denotes the number of the elements in the pre-set of x, e.g. $\|pre(x_8)\|=2$.

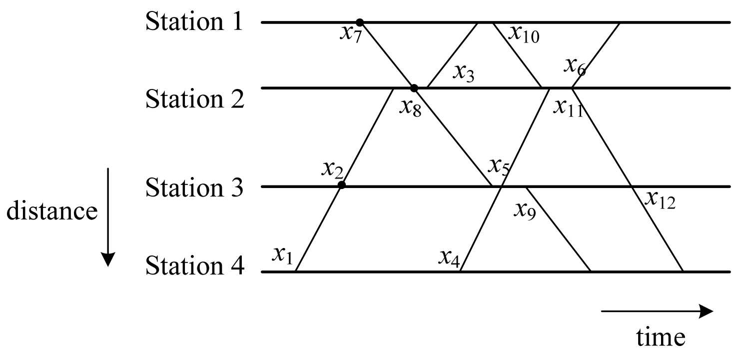

Figure 1 Train Service Diagram

Hence, the delay probability resulting from the *pre*(x) with T minute delay is computed by

$$P_{pre(x)}(t \geq T) = [1-(1-\exp(-\lambda))^{\|pre(x)\|}]^T \qquad [7]$$

When delay occurs, it is desirable to keep the trains to be affected as minimal as possible. The *post*(x) i.e. post-set of x, is defined as the set of trains that are influenced by train x, e.g. $\text{post}(x_8)=\{x_3, x_5\}$. Similarly, $\|post(x)\|$ is the number of the elements in the post-set of x. For this index, $\Sigma\|pre(x)\|$ and $\Sigma\|post(x)\|$ are regarded as the indicators.

Robustness

The robustness of the timetable can be regarded as the recovery capability. The recovery matrix $\boldsymbol{R} = (r_{ij})$ shows the recovery ability of a timetable.

Let Ω be the set of all train activity events i.e. departure and arrival events scheduled by a timetable, and $y_i^l \in \Omega^l \subseteq \Omega$ be the *i*th event at station *l*, where Ω^l is the set of events at station *l*, and I_{ij}^l is the minimum headway time to keep the safe distance between the two adjacent trains. Then, r_{ij}, the *ij*th entry of the recovery matrix in one direction is calculated by

$$r_{li} = y_{i+1}^l - y_i^l - I_{ij}^l \qquad [8]$$

The recovery matrix of the train service schedule in Figure 1 is given as below.

$$R = \begin{bmatrix} 0 & 6 & 0 & 0 & 0 \\ 0 & 0 & 6 & 0 & 0 \\ 0 & 3 & 2 & 28 & 0 \\ 34 & 0 & 28 & 0 & 0 \end{bmatrix}$$

The zeroes in the recovery matrix indicate that the events must not be delayed. Otherwise delay propagation will arise.

The indices above are greatly related to the passengers. The time spent on the travel, particularly on the waiting and transfer, is desirable to be less for the passengers since everyone wants to get to his destination as soon as possible. The time cost shows much concern on this need of the passengers. Besides, the index of transport capacity estimates if the railway operator provides sufficient seats for the passengers with the comfort considered by the factor η. The delay probability and robustness evaluate the punctuality of the train services which is also concerned by the passengers.

By the above indices, a general evaluation on the passenger service quality of the railway timetable is possible. If the result for the evaluated timetable is not satisfactory, adjustments are needed to enhance the schedules.

ENHANCEMENT FOR THE SCHEDULES

Objectives

It is always preferable to keep the overall traveling time minimum. The first objective is the minimum time cost.

$$\min T = T_1 + T_2 + T_3 \qquad [9]$$

The objective for the transportation capacity is considered to be minimal deficiency between it and the passenger transportation demand.

$$\min P = |\eta D - C_t| = |\eta D - n\overline{c}| \quad [10]$$

The adjustment on delay probability is trying to reduce the number of elements in the pre-set and post-set.

$$\min N = \sum \| pre(x) \| + \sum \| post(x) \| \quad [11]$$

In order to improve the robustness, the optimal objective may be the minimum number of zeros in the recovery matrix under the condition that the transportation demand is satisfied.

$$\min N(0) \quad [12]$$

Constraints

As described above, the timetable enhancement is a multi-objective programming problem which follows the constraint below.

The dwell time of the train service should guarantee the alighting and boarding of the passengers, as well as maintenance for the train.

$$t_i^d \geq t_{\min} \quad [13]$$

Some passengers may opt for other transportation modes if they feel the waiting time exceeds their expectation for transfer. In order to avoid excessive waiting time for the transfer passenger, the upper limit is set according to the passengers' expectation, namely $\max W$ (He, 2006). The lower limit is to satisfy the minimum time needed to transfer at the station.

$$\min T \leq T_3 \leq \max W \quad [14]$$

The buffer time should be appropriate to keep the total time taken by the train services and buffers from exceeding the cycle time (T_c) or the available time.

$$\sum_{i=1}^{n-1} (T_i^d + I_{i(i+1)} + r_{i(i+1)}) + T_n^d + I_{n1} + r_{n1} \leq T_c \quad [15]$$

Furthermore, according to Sun (1998), $\|pre(x)\|=1$ or 2, and $\|post(x)\|=1$ or 2.

Heuristic algorithm

Because the objectives do not comprise the same variables and some objectives need manual adjustment such as the objective [11] and [12], the problem could not be solved by the algorithm commonly used such as linear weighted method for the multi-objective programming problem. A heuristic algorithm is presented to solve this problem. In order to avoid conflict between the transportation capacity and buffer time, the priority of them should be determined first. In most situations, the railway operator would like to give priority to the former, namely transportation capacity, so does this study.

- if $C_t > \eta D$, the following adjustments can be made to improve the timetable.

(i) try to reduce train service in order to add buffer time;
(ii) adjust the trains departure time to meet the transfer time requirement;
(iii) reduce the dwell time to the minimize the time cost.

- if $C_t \leq \eta D$, then,

(i) remove all the buffer time;
(ii) reduce the dwell time to minimize the time cost;
(iii) increase train service under the constraint [15];
(iv) re-plan the buffer time;
(v) adjust the trains departure time to meet the transfer time requirement.

The method of the adjustment above is a kind of expert view. It is very practical without complex computation. However, because many factors are involved in the railway timetable scheduling, such as the cooperation between different lines or railway companies, the adjustment can only be applied to part of the timetable. So it may be called partial adjustment. A feasible solution but maybe not the best one is going to be found after the adjustment.

CASE STUDY

Setup

The Yangtze Delta is one of the well developed areas in China. The major cites in the region are Shanghai (SH), Nanjing (NJ) and Hangzhou (HZ). Thousands of people are frequently traveling among these three cities. The railway from NJ to SH and then to HZ, which is called Hu-Ning-Hang (SH-NJ-HZ) railways, have been one of the busiest ones in China. Table 1 shows the lengths and yearly transportation density of the railways from NJ to SH and SH to HZ.

In this case study, an evaluation on the train service schedules of the

Hu-Ning-Hang railways will be performed, and some adjustment will be put forward subsequently. The busiest time periods of the NJ-SH and SH-HZ railways are 11:00 to 16:00 and 14:00 to 19:00 respectively, which are the periods that this paper studies.

Table 1 Yearly Transportation Density

Direction	NJ-SH		SH-HZ	
	Length(km)	Density($\times 10^3$)	Length(km)	Density($\times 10^3$)
Up-ward	331	31319	201	17498
Down-ward	331	32114	201	18691

Data Source: Railway Statistics of China in 2004

Evaluation

It is quite satisfactory that the average waiting time at the stations in Hu-Ning-Hang railways is less than 15 minutes as Table 2 shows. The total distance of the railways is 532km. As the average travel time is 5.35hr, the average travel speed of the train is close to 100km/h which is relatively fast in China. Because some connection trains do not connected at the same station (SH has two major stations), the average transfer time is slightly high. The transportation capacity evaluation shows the scheduled transport capacity of SH-HZ line is much higher than required. As for the robustness, there are 48 zeros in the recovery matrix. Since the number is desired to be the minimum, it is not good enough.

Table 2 Evaluation on Train Service Schedules

	Indices		Maximum	Minimum	Average/Scheduled
Time cost	Waiting time		42min	5min	13.2min
	Travel time		8hr 13min	3hr 26min	5hr 21min
	Transfer time		3hr 26min	26min	1hr 28min
Transportation capacity($\times 10^3$)	NJ-SH	Scheduled		27.7 (η=1.2)	
		Required	32	18	23
	SH-HZ	Scheduled		22.2 (η=1.7)	
		Required	19	11	13
Delay Probability	$\Sigma\lVert pre(x)\rVert$		-	-	342
	$\Sigma\lVert post(x)\rVert$		-	-	342
Robustness	$N(0)$		258	0	48

Note: η= scheduled capacity/average TD.

In the following section, some adjustment is going to be made to get the timetable improved.

Enhancement

In the train service schedules of the Hu-Ning-Hang railway, most trains of Z-type, T-type and K-type depart from other cities beyond the Yangtze Delta area. It is impossible to reschedule these trains. While some D-type and N-type trains depart from NJ or SH, and only run in the sections in the area, they are the right trains that the adjustment can be made. Table 3 and 4 show the rescheduled and cancelled train services respectively.

Table 3 Rescheduled Train Services

No.	Dep.	Arr.	T.T.$_1$	Conn.No.	Dep.	Arr.	T.T.$_2$	Tot.	Tran.
D425	12:46	14:59	2:13	K111	16:13	18:31	2:18	4:37	1:14
D427	12:56	15:09	2:13	K181	16:19	18:37	2:18	4:31	1:10

Table 4 Cancelled Train Services

No.	Dep.	Arr.	T.T.
N467	15:02	17:41	2:39
N425	17:34	20:16	2:42

Table 5 Re-evaluation on Train Service Schedules

Indices			Maximum	Minimum	Average/Scheduled
Time cost	Waiting time		36min	5min	12min
	Travel time		8hr 13min	3hr 26min	5hr 21min
	Transfer time		3hr 26min	26min	1hr 29min
Transportation capacity($\times 10^3$)	NJ-SH	Scheduled		27.7 (η=1.2)	
		Required	32	18	23
	SH-HZ	Scheduled		19.6 (η=1.5)	
		Required	19	11	13
Delay probability	$\Sigma\|\|pre(x)\|\|$		-	-	322
	$\Sigma\|\|post(x)\|\|$		-	-	322
Robustness	$N(0)$		258	0	43

The results by the re-evaluation in Table 5 show that, no travel time is reduced. This is because the dwell times have already been minimized by the railway operator. Nevertheless the average transfer time rises 1 minute, the maximum waiting time is reduced by 6 minutes, and average waiting time is reduced by 1 minute. After the adjustment, the scheduled transport capacity of the SH-HZ line gets much lower. The delay probability and robustness are both improved as the excessive train services are cancelled.

Discussion

From the viewpoint of the passengers, the quality of railway timetable depends on if it can satisfy their demands and provide a fast and smoothly transport service. According to these, the indices proposed by this study focus on the aspects of the timetable that show the needs of passengers.

From the case study, the proposed indices are easy to be figured out in terms of the timetable, which shows they are practical. The timetable of Hu-Ning-Hang railways is improved by the adjustment. However, it is limited by the travel distance of some trains. So the enhancement is partial because the method is incapable for a railway network.

CONCLUSIONS

Four types of criteria to evaluate the service quality of the train service schedules are presented in this study. The time cost evaluates the time that the passengers spend on their travel. Transport capacity measures if the transportation demand could be satisfied. The indices of delay probability and robustness evaluate the probability that the scheduled train services are likely to be delayed and the recovery ability of the timetable after delay has occurred.

Adjustment is needed to improve the problems disclosed by the evaluation. A multi-objective model as well as a heuristic algorithm is proposed. Because the railway timetable is a complex system, partial modifications are more likely to be made if the full-side rescheduling is impossible or not necessary.

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